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NAVAL RESEARCH LABORATORY (SDIO/IST)

FINAL TECHNICAL REPORT

FOR

May 9, 1989 through May 8, 1990

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CONTRACT: ONR N00014-89-K-2020

TITLE OF CONTRACT: Narrow gap superlattices for infrared sensor applications

NAMES OF PRINCIPAL INVESTIGATOR: Wen I. Wang, Professor

NAME OF ORGANIZATION: Electrical Engineering Department, Columbia University

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The research performed under this contract started on May 9, 1989 and ended on May 8, 1990. The emphasis of our research under this program is to obtain high quality narrow gap superlattices for infrared sensor applications.

During this initial phase of research, all the fundamental work necessary for future achievement of high quality metastable materials has been completed. This work includes the growth of all the various buffer layer materials such as InAs, InSb, GaSb, and AlSb, the calibration of the Auger system for quick feedback of alloy composition, and the in-situ RHEED oscillation calibration of growth rate. The following multilayer structures and metastabble compounds have been grown and analyzed:

1. Study of the detailed surface structure of AlGaSb and GaSb/AlSb multilayer structures: During the buffer layer studies, we found that the growth of InAs, GaSb and AlSb is compatible in the temperature range of 450°C - 500°C. We have studied the surface structures of GaSb, AlGaSb, and alternating GaSb/AlSb layers using 10 kV reflection high energy electron diffraction. We studied AlSb and GaSb grown from elemental Ga and Al, and Sb_4 sources. We observed that the $c(2x6)$ structure is the dominant surface phase for substrate temperatures between 400 °C and 600 °C under Sb-stabilized conditions. Above 540 °C, depositing sub-monolayer quantities of Ga on the Sb-stabilized surface changed the $c(2x6)$ pattern to (1x3). With further Ga deposition the pattern changed to $c(8x2)$, a Ga-stabilized surface. Even with the higher growth temperature, the $c(8x2)$ pattern is not completely reproducible. Thus, a temperature of 540 °C is a necessary but not sufficient condition for obtaining this pattern. Nonetheless, our results show for the first time that the $c(8x2)$ metal-stabilized surface, which has been observed on all other III-V arsenides, phosphides, and antimonides, is in fact a universal feature of III-V compound surfaces. This evidence suggests that bond-pairing occurs on all (100) III-V surfaces and may even be a universal reconstruction for surfaces of all tetrahedrally coordinated semiconductors.

For alternating GaSb and AlSb depositions grown between 500 and 600 °C, smooth patterns persist, indicating that atomically smooth GaSb/AlSb interfaces can be formed. The Sb-stabilized GaSb surface $c(2x6)$ has a sharp transition to the AlSb (1x3) surface. This result is quite different from what occurs in the overgrowth of AlAs on GaAs. For AlAs overgrowth on GaAs between 620 °C and 680 °C, diffuse (2x4) or (2x1) patterns

persist for more than 10 monolayers of AlAs deposition, occasionally up to more than 20 monolayers. In contrast, below 600 °C, the transition from (2x4) to a disordered (1x1) surface is immediate. Thus, it seems that at the higher temperatures, aluminum "knocks out" gallium and enough gallium segregates to the surface to affect the reconstruction. This interpretation of the transient (2x4) or (2x1) structure is confirmed by Auger analysis which shows the surface accumulation of Ga, very much similar to the case of Sn segregation in GaAs.

The conclusion from these results is that the AlAs bond is stronger than the GaAs bond, while the AlSb and GaSb bond strengths are more nearly equal. If the temperature is high enough in the growth of bulk AlAs, the substrate energy can compete with the bond energy. As a result, the excess surface As can reevaporate and the Al adatoms will have long enough surface migration length to be incorporated into the right lattice sites. In this regime, the ordered (3x2) and *c*(8x2) structures will appear. At the other extreme, if the temperature is too low, the Al will not be able to displace Ga at the surface and the disordered (1x1) will appear right away. For intermediate temperatures, the transient structures will be observed.

Despite many years of study, no model for the threefold reconstructions has emerged. Although the RHEED patterns of threefold reconstructions on AlAs, AlSb, and GaSb are streaky, indicating reasonably planar surfaces, it seems clear that the threefold reconstruction is associated with the presence of a species with high sticking coefficient or low surface mobility, such as Sb or Al. Thus, the antimonides show "three by" patterns while the arsenides would show "two by" surfaces. In the case of AlAs and AlGaAs, however, the large bond energy induces disorder and shows "three by". Across the whole AlGaSb alloy range, Sb-stabilized surfaces show diffuse reconstruction patterns, indicating disorder exists on the surface. However, as demonstrated here, at high substrate temperatures, metal-stabilized twofold reconstruction of AlGaSb can always be obtained, suggesting again that bond-pairing is a universal reconstruction mechanism in all the III-V compounds. The results were presented at the 10th U.S. MBE workshop.

2. MBE growth of single crystal metastable GeSn alloys on InP and GaSb substrates: This is the first time single crystal GeSn alloys have been grown on lattice-matched GaSb and InP substrates. Previous published work was all on the growth of polycrystalline GeSn, even by MBE, presumably due to the mismatched substrates used

(Ge instead of GaSb and InP). We have shown that metastable GeSn can indeed be obtained; however the critical thickness appears to be too thin to be useful for detector applications. Above approximately 300 nm, dislocations set in and destroyed the metastability and the β-Sn phase appeared. The conclusion of our study is that growth of metastable GeSn alloy films to a thickness more than 0.3μm is very difficult. We have shown theoretically, by energy balance theory, that the critical thickness is a very steep function of the lattice mismatch. Under practical MBE conditions, it is very difficult to control the alloy composition to within 2%. Deviations from the exactly lattice-matched composition will cause the formation of β-phase GeSn. The paper was presented at the 10th U.S. MBE workshop.

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